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Progress Report - Season of 1939

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March 8, 1940

NATIVE PREDATORS OF THE MOUNTAIN PINE BEETLE IN SUGAR PINE

Progress Report—Season of 1939

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NATIVE PREDATORS OF THE MOUNTAIN PINE BEETLE IN SUGAR PINE

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INTRODUCTION

Investigative work on mountain pine beetle predators was initiated by the Berkeley Forest Insect Laboratory, Bureau of Entomology and Plant Quarantine in 1937. The objectives set up were:

1. To determine the importance of predators as biological control factors and what may be done to protect them and encourage their development under field conditions.

2. To investigate the possibilities of artificial propagation to increase populations in excess of normal development in the field.

These two objectives have been followed in all subsequent work carried on at Berkeley and in the field near Wawona, California.

The initial work revealed that the red bellied clerid Enoclerus sphegeus and the green trogositid Temnochila virescens, by reason of their constant association and number were more important than several other species found. The findings since then have quite positively confirmed the original work. Detailed studies on the life history, habits, and controlling effect of these two insects in the field under natural conditions and in laboratory controlled rearing experiments have resulted in comparative evaluations tending to limit the possibilities of each predator. Some of these results are compiled in reports by the writer during 1938 and 1939,* and some are included in this progress report.

The work on artificial propagation has shown definitely that it is possible to rear successfully in numbers the green trogositid in the laboratory. The red bellied clerid was found much less adaptable to the conditions of rearing and technic applied, and rearing experiments were discontinued with this insect.

This report covers the seasonal progress during 1939 and the results of artificial rearing experiments started in 1938 and completed in 1939. It has been divided into two sections to separate the presentation of results of studies of the effect of predators on bark beetle populations in the field from that of the laboratory technic of rearing predators. The first section deals with data and experiments on the controlling effect of predators in relation to the mountain pine beetle. The second section includes more recent developments and results of artificial propagation tests.

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* See references cited.

SECTION I—EFFECT OF PREDATORS ON MOUNTAIN PINE BEETLE POPULATIONS

The occurrence and relative numbers of predators among the broods of the mountain pine beetle beneath the bark of an infested sugar pine may profoundly affect population increases by limiting the number of emerging adults. The degree to which this occurs may in part be limited by preferences shown by predators for the mountain pine beetle in favor of other tree killing insects and in part by the degree of synchronism in development between the predator and its host. The investigations during 1939 on the biological control of the mountain pine beetle set out to answer these questions:

1. Is there any correlation between the number of predator larvae of a given species and the reduction of mountain pine beetle broods?

2. On what other hosts are the predators of the mountain pine beetle found and does this limit their effectiveness in controlling the beetle?

3. How does the lack of synchronized development between predator and host affect the controlling efficiency of the predator?

4. What is the maximum effect of a given predator in controlling the mountain pine beetle?

1. Relative Numbers of Predator Larvae and Advanced D. monticolae Brood Stages.

In these studies, population data were taken on all the insects found beneath a 10 square foot area of bark, representing the average condition of mature D. monticolae brood (fully grown larvae, pupae, and callow adults). During 1938, the data in this way indicated some rather positive correlations between the number of T. virescens larvae and the D. monticolae populations developed, but no correlations were indicated with the presence of other predator species.

During 1939 population data were taken from 29 infested trees, of which 15 contained the 1938-1939 overwintering broods and 14 contained the summer (1939) broods. Nine of the trees occurred on the Signal Peak area, 16 in Mariposa Grove, and 4 on miscellaneous areas in the vicinity of the Miami laboratory. A summary of these data best representing the average winter and summer broods is shown by Table 1.

Table 1. Number of predators, associates, and D. monticolae per unit of bark area among overwintering and summer broods.

Tree No.	Area of Sample (sq.ft.)	Predators per square foot T.v.c.	E.sph.	All others*	Associates** per square foot	D.m. per square foot
			Overwinter 1938-1939			
1	10	0	9.1	5.5	.5	255.1
2	10	0	1.6	4.9	.5	192.3
3	10	0	16.9	2.3	9.5	152.8
4	10	0	4.7	1.2	10.4	178.3
5	10	0	2.6	9.8	8.9	164.0
7	10	0	7.7	3.6	4.7	155.6
14	10	0	13.8	4.7	.0	108.7
15	10	0	11.9	1.4	.1	116.3
			Summer 1939			
5	10	0	.5	7.2	.1	21.8
6	10	1.8	.0	2.5	2.0	90.8
7	10	.7	.3	7.3	1.7	33.2
8	10	1.6	1.2	14.5	3.1	60.8
9	10	.8	.2	4.8	.0	35.7
11	10	.2	.0	2.2	.5	12.7
13	10	.9	.4	5.3	.8	40.4
16	10	.9	.0	1.0	.0	47.8

* Medetera aldrichii, Platysoma punctigerum, Plegaderus nitidus, Aulonium longum, Nudobius sp., Tenebroides sp.

** Flatheads, roundheads, Pityophthorus, Corticius

The most significant facts determined by these data are:

1. No correlation was evident between the number of predator larvae present, regardless of species, and mountain pine beetle brood populations. The apparent reason for this result is that a large proportion of the predator larvae found at the time of analysis were in the young larval stage, and consequently had not yet destroyed an appreciable amount of brood. This indicates a definite weakness in the method of securing information. It may be corrected by rearing the D. monticolae from a given area of bark to the adult stage in tightly enclosed cages or containers to prevent the escape of any of the insects beneath. By use of cages any effect the predators have on maturing D. monticolae broods should be shown by the number of emerging adults.

2. The overwintering (1938-1939) D. monticolae populations outnumbered the summer populations by four times, even though the total overwintering predator populations outnumbered the summer populations by two times. This seems to indicate that some factor or factors apart from the predators or associated insects affected the summer brood.

3. So far as this data indicates, there is no correlation between the predator larvae of a given species and reduction of mountain pine beetle broods.

2. Occurrence of Predators with Other Hosts.

The efficiency of a predator in controlling D. monticolae is measured in part by its tendency to prefer to attack that host among several others. This factor was measured by making predator population studies among several scolytid hosts, a flathead, and a roundhead, during 1939 in several different tree species. In this study 5 trees containing overwintering infestations of the various insects and 15 trees containing summer infestations were felled. Counts were made on the number of T. virescens, E. sphegeus, and M. aldrichii in measured areas of bark found to contain a given infestation. A total bark area of 205 square feet was covered by these counts. The results are summarized in Table 2.

Table 2. Association of predators with other hosts

Association	Tree spec.	No. Trees	Bark area (sq.ft.)	Predators found--per sq. ft. T.v.c. larvae	E.sphegeus larvae	Medetera ald. larvae
Overwintering broods						
D. jeffreyi	JP	1	10	0	6.2	0
D. monticolae	PP	1	5	4.4	15.0	0
Pityophthorus sp.	WF	1	5	1.6	0.0	1.3
Pseudohylesinus	WF	1	5	2.2	0.6	1.4
Summer broods						
D. brevicomis	PP	4	35.8	.7	.009	.009
D. jeffreyi	JP	2	14.8	.08	.06	1.48
Ips confusus	JP	1	3.0	.66	.0	.66
Ips emarginatus	JP	1	10.0	.10	.4	.00
S. ventralis	WF	2	20.0	1.00	.06	4.60
Hylurgops sp.	JP	1	5.0	1.6	.0	13.40
T. abietis	WF	1	10.0	.4	.0	.1
Semanotus sp.	IC	2	27.2	.44	.0	.0
M. gentilis	SP	1	20.4	.03	.0	.0

While these data are by no means conclusive, they strongly indicate that these predators are limited in their effectiveness in the control of the mountain pine beetle because:

1. None of them was found to be entirely specific on that host.

2. With the exception of E. sphegeus, the other two predators were as commonly associated with other hosts as with the mountain pine beetle.

3. E. sphegeus was shown to be equally associated with the mountain pine beetle and the Jeffrey pine beetle, but was not found to be as general in distribution as the other predators.

These data indicate that none of the predators studied could be relied on as a specific controlling agency against the mountain pine beetle, and hence the effectiveness of any particular species is thereby definitely limited.

3. Efficiency of Predators affected by Lack of Synchronized Development with D. monticolae.

The average life cycle of T. virescens requires one year from the egg to the adult stage. Two complete life cycles are generated by the host D. monticolae during this same time. Naturally if this is the case, how can T. virescens alone exert an appreciable controlling effect? Furthermore, if the larvae of T. virescens have developed only partially by the time D. monticolae broods have completed their development and emerged, what must they live on to complete development? Do they feed on supplementary hosts, migrate to other areas containing D. monticolae brood, or perish?

In order to answer these questions the following observations were made:

Two trees were felled. One was a ponderosa pine which had been killed by D. monticolae and D. brevicomis during 1938. The other tree was a sugar pine attacked in the top by D. monticolae during the summer of 1938 with a 1939 winter brood of larvae, pupae, and adults below. The ponderosa pine contained T. virescens larvae in excellent condition. All evidence of pine beetle broods had gone, but there were many roundhead (Graphisurus) larvae upon which the predators were feeding and maturing.

In the top half of the sugar pine T. virescens larvae were found, but these were in very poor condition. In 15 square feet of bark examined there were 21 larvae. Fifty percent of them were emaciated. One was dead. The bark was quite dry. No larvae were found in the area lying immediately below, which contained a good brood of D. monticolae.

These observations indicate that the survival of T. virescens larvae is dependent entirely on secondary hosts or cannibalism, following the complete development and emergence of D. monticolae. If secondary hosts are sparse or lacking the survival of this predator is evidently impaired and starvation may be the result. No evidence was found to indicate that they migrate to another source of food, as shown by the sugar pine which contained an excellent source of food lying immediately below on the same tree on which the predators were established.

The controlling efficiency of this predator is definitely affected by the reduction in populations through cannibalism or starvation, caused by its failure to migrate to adequate sources of host food. These data further indicate that the maximum controlling effect against the mountain pine beetle is limited to the brood on which this predator was first established.

4. Maximum Efficiency of Predators under Controlled Cage Conditions.

The maximum effect of a given predator in checking the development of the mountain pine beetle cannot be determined except by controlled rearing under conditions provided by caging to exclude all except the predator to be studied. In 1937 and again in 1938 these conditions were provided by screen cages and insectary rearing units where the effect of T. virescens and E. sphegeus in separate experiments was tested. In each experiment with a given predator, green logs freshly infested with D. monticolae were used, half of which were kept free from predators to compare the development and emergence of D. monticolae broods with those in which the predators were admitted.

T. virescens was found to be highly effective in all tests, with the controlling effect running between 80 and 90 percent as compared with checks (determined by counts of emerged beetles). In all tests with E. sphegeus no control was evident, and this was apparently caused by the failure of this insect to become adapted to the confined conditions of the experiments. As a result in subsequent experiments continued in 1939 E. sphegeus adults were excluded.

The results of previous work by use of adults to lay eggs and establish brood led to the question of how many larvae were needed for effective control. Is it possible to plant eggs or larvae on infested logs and expect effective control? In supplementary investigations carried on in 1939 tests with predator adults were supplemented by tests with varying numbers of eggs and larvae.

In setting up each of these experiments great precaution was exercised to exclude all predators except those to be studied. All joints of the cage compartments were sealed with cotton or putty. Weather stripping was used around the doors to secure a snug seal. The floors were swept and the cages were examined closely on the inside before the start of an experiment to assure the lack of predators which may be lurking inside.

Even with these precautions, every experiment was upset by the presence of T. virescens larvae in the checks. It is not known where they came from, but these sources are strongly suspected: (1) In two instances adults were found inside, which may have entered when the door to the cage was opened (when found they were killed); (2) Eggs may have been laid on the logs before they were placed in the cage; (3) Larvae may have migrated and gained entrance to the cage because of insufficient sealing. Whatever the source, it is obvious that greater precautions will have to be taken in further tests of this kind.

The results of these experiments are herein presented.

Control by Planting T. virescens Adults

Fifteen logs were used in this test conducted in two compartments of the large screen rearing unit at Miami Laboratory. Eight logs having 88.4 square feet of bark area were placed in compartment 1 where the predators were excluded. Seven logs having 83.5 square feet of bark area were placed in compartment 2 where 30 pairs of T. virescens adults were admitted. Both groups of logs were infested by D. monticolae at the same time at the rate of 20 per square foot, 72 hours before the predators were admitted to compartment 2. The test was started June 3 and ended August 30, 1939, when all the D. monticolae adults of the new generation had emerged. Results are tabulated as follows:

Logs	Number of Insects Attacking		Number of Progeny		Percent Control
	D.monticolae	T.virescens	D.m.adults	T.v.c.larvae	
Check	1,768	0	2,449	15	
Control	1,670	60	178	71	93

The excellent control shown is consistent with the test conducted in 1938 using identical methods. The 1938 test resulted in 91 percent control.

The effect of adult predators controlling D. monticolae parent adults from evidence secured on parent adult emergence was indicated in this test. In the check cage 168 parent adults emerged while 12 emerged from the T. virescens control cage. The evidence here indicates that this may profoundly affect the number of progeny produced, not considering the controlling effect of T. virescens larvae.

The 15 T. virescens larvae found in the check cage indicated contamination, resulting possibly from insufficient sealing between the two cage compartments or from adults which had gained entrance through the door. The apparent lack of any controlling influence shown by these larvae strongly

indicates that they had not been in with the D. monticolae broods sufficiently long to affect their numbers. This number of predator larvae in relation to the control shown is obviously out of proportion to the amount of control indicated by the 71 larvae in the predator control cage.

The number of T. virescens larvae found beneath the bark following complete emergence of D. monticolae adults is by no means indicative that they alone were responsible for the control. On the contrary, previous experiments have shown that from 8 to 10 times this number of young larvae may be established, but the original number is cut down later either as a result of cannibalism or of migration.

Control by Planting T. virescens Eggs

In this test 6 logs each having 5 square feet of bark area were infested by D. monticolae at the rate of 20 per square foot. Following the attack on the logs by the adults, T. virescens eggs were planted in the bark crevices, varying in number on each log from 10 to 40 per square foot. Eggs were not planted on one of the logs which was used as a check. The test was conducted in two compartments of the rearing unit; the T. virescens logs in one unit separated from the check log in another unit. This experiment was conducted between July 13 and September 21, 1939. On the latter date counts were made on all stages of brood after some emergence had begun. Over 70 percent of the brood was in the adult stage. The results were inconsistent as shown by Table 3.

Table 3. Control of D.m. by T.v.c. larvae developed from eggs planted in bark crevices.

Log Number	T.v.c. eggs planted	D.m. brood total	T.v.c. larvae recovered
1	50	30	13
2	75	54	4
3	100	28	6
4	150	13	16
5	200	13	16
6	Check	36	15

Contamination by T. virescens larvae again occurred in the check log and rendered it valueless. The small broods produced in each of the logs indicates that the T. virescens exerted considerable control. Normal brood development without interference from predators in logs varies between 70 and 100 to the square foot. At these figures the control is estimated to vary between 87 and 97 percent. This test will need repetition before positive conclusions are drawn on the effect of varying numbers of predators per unit of bark area.

Control by Planting T. virescens Larvae

In this test newly hatched T. virescens larvae were used as the controlling agency. Ten green ponderosa pine logs numbered 1 to 10, each having a bark area of approximately 6 square feet, were attacked by D. monticolae adults in separate muslin type cages set inside two compartments of the screened rearing unit. Logs 1 to 5 were placed in one unit and logs 6 to 10 were placed in the other unit. Logs 5 and 10 were used as checks while T. virescens larvae varying in number from 3 to 10 to the square foot were introduced on the other logs, first attacked by D. monticolae adults at a rate of 20 per square foot of bark area. The experiment started July 8 was completed September 12, 1939 when about 75 percent of the D. monticolae brood had reached the adult stage; as shown by Table 4 which follows, these results were also inconsistent.

Table 4. Control of D.m. by T.v.c. larvae planted directly to bark crevices.

Log Number	T.v.c. larvae introduced	Total D.m. brood	T.v.c. larvae Recovered
1	18	92	0
2	24	30	16
3	30	47	1
4	36	12	5
5	Check 0	25	5
6	48	9	6
7	54	47	1
8	60	26	7
99	72	16	17
10	Check 0	89	1

Here again, as with the T.v.c. eggs, contamination entered into the checks nullifying their use as such. No correlation was noted between the number of predator larvae introduced and the amount of control. The migration of larvae would explain such inconsistencies. Compared with normal development in uncontaminated green logs, the control in this experiment varies approximately between 83 and 99 percent.

The inconsistencies and contaminations evident in this test require repetition before conclusions can be drawn on the comparative effectiveness of varying numbers of larvae.

Control by Planting E. sphegeus Larvae

In this test E. sphegeus larvae taken from infested trees in the field were used. Three green ponderosa pine logs were infested by D. monticolae at the rate of 20 per square foot. Fifty-four E. sphegeus larvae were introduced to each of two logs after the D. monticolae had become established. The third log was left as a check. Each log which contained 5 square feet of bark area, was placed in a separate cage. The test was started July 11 and ended August 11, 1939, when all adults of the new brood had emerged. These results were obtained.

Table 5. Control of D. monticolae by E. sphegeus larvae

Log number	E.spheg. larvae introduced	D.m. adults emerged	E.spheg. larvae recovered	T.v.c. larvae	Percent control
1	54	253	0	5	44
2	Check 0	452	0	0	
3	54	104	0	2	72

The control results represented here were probably caused by a contamination of T. virescens larvae and not be E. sphegeus since the E. sphegeus larvae either migrated, died, or were also eaten by the T. virescens larvae. A normal brood developed in the check log.

Conclusions and Suggestions for Further Study

The conclusions to be drawn from these tests are: (1) That the control by use of T. virescens adults in preying on adult D. monticolae and by larvae which prey upon the brood is highly effective under the conditions of the experiment; (2) That control by use of T. virescens eggs or larvae may be effective, but the conditions of the tests conducted resulted in inconsistencies requiring their repetition under perfected conditions to prevent contamination; (3) That no control was apparent by use of E. sphegeus larvae, but inconsistencies and contaminations in the test require that it be repeated.

The effect of T. virescens adults in preying upon attacking mountain pine beetle adults may be an important factor in limiting mountain pine beetle populations. This factor may also be shown by E. sphegeus adults. In further experiments this phase of predator control should be thoroughly investigated.

SECTION II - ARTIFICIAL PROPAGATION OF MOUNTAIN PINE BEETLE PREDATORS

Tests to determine the possibility of developing predators in the laboratory were begun during the fall of 1937 at Berkeley and continued in the field at Miami during the summer, 1938. Methods and technic in handling and developing the younger stages and in rearing them to maturity under artificial conditions seemed to offer considerable promise, since through their application populations could be increased considerably. All tests were conducted with T. virescens and E. sphegeus. E. sphegeus was found to be much less adaptible to the methods applied.

Several questions resulted from this investigation and these must be answered before it is known whether artificial propagation is feasible. The 1939 seasonal program was developed and undertaken to answer these questions:

1. Is the survival to healthy adults reared under artificial methods and conditions high enough to justify continued investigations directed toward the improvement of artificial propagation technic? Is the cost justified?

2. Are laboratory reared adults as prolific as adults taken from the field?

3. Is the period of larval development influenced by differences in amounts of host food consumed, or is it predetermined by inherent qualities?

The first question was partially answered by two large scale rearing set-ups established during the summer of 1938, the final results of which were not determined until development was completed in 1939. One set included 537 E. sphegeus larvae, and the other included 1083 T. virescens larvae, all of which were developed from eggs deposited in the laboratory by adults taken from infested trees in the field. The other questions applicable to T. virescens were answered in part by experiments set up to test them out.

1. Survival of Laboratory Reared Predators in Relation to Continued Investigation and Cost.

Enoclerus sphegeus

These larvae were set up at weekly intervals from June 27 to August 23, 1938 as more eggs were laid and incubated in the laboratory. They were fed every 2 days during the course of larval development. Some of the first larvae set up, pupated and emerged within 8 weeks. The others spent the winter in the larval stage in the basement of the Miami Laboratory.

Activity was resumed after April 15, 1939. The experiment was closed July 27, 1939 when all the brood had died or turned into adults. The results are summarized in Table 6.

Table 6. Results of Artificial Propagation of E. sphegeus Begun at Miami Laboratory - 1938.

Series Number	Number set up	No. of adults	Mortality No.	Mortality %	Days required to rear adults Minim.	Days required to rear adults Maxim.	Date set up 1938
38-A	21	17	4	19.1	78	108	6/27
38-B	20	14	6	33.3	80	292	7/1
38-C	35	18	17	48.5	71	276	7/7
38-D	58	36	22	34.4	73	270	7/13
38-E	98	31	67	60.0	73	261	7/20
38-F	88	39	49	47.8	77	254	7/26
38-G	106	12	94	88.6		250	8/2
38-H	98	5	93	94.0		284	8/15
38-I	13	2	11	84.0		300	8/22
Totals	537	174	363	68			

The total survival for this experiment amounted to 32 percent. The mortality was divided between larvae (44 percent) and pupae (24 percent). Many of the adults were imperfectly formed and most of them were undersized. These results indicated definitely a lack of adaptability to the rearing methods, and do not justify continuing artificial propagation of this insect until a method specially adapted to this insect is found.

Temnochila virescens (Fab.)

In this experiment 1083 newly hatched larvae were set up individually in one dram pharmaceutical vials between June 27 and August 24, 1938. These were fed every two days during the summer and fall by dropping one living D. monticolae larva into each vial. On October 24, 1938 the entire lot of larvae was placed in the basement at the Miami Laboratory and left to hibernate during the winter months without further feeding. All of the larvae, except those set up after August 1, 1938 were fully grown by October 24. On April 14, 1939 the larvae were examined and kept at room temperature in the laboratory. Those requiring food were fed twice weekly until fully grown. Table 7 presents a detailed summary of this experiment.

Table 7. Results of Artificial Propagation of T. virescens Miami Laboratory - 1938.

Series Number	Number set up	No. of adults	Percent Mortality	Days required to rear adults Minim.	Maxim.	Date set up 1938
38-A	15	13	13.3	378	402	6/27
38-B	12	9	25.0	377	391	7/1
38-C	56	34	39.3	351	398	7/7
38-D	140	133	5.0	358	392	7/13
38-E	57	48	15.1	357	379	7/19
38-F	87	84	3.0	344	372	7/26
38-G	95	72	24.2	333	373	8/1
38-H	193	162	16.0	319	366	8/8
38-I	257	213	17.0	324	365	8/15
38-J	171	104	36.0	315	384	8/24
Totals	1,803	872	20.0			

The survival for the entire lot amounted to 80 percent. Mortality occurred only in the larval stage. All the pupae transformed into adults which were apparently normal in every respect. This experiment was highly successful, and leaves little doubt as to the adaptability of Tenmochila to the rearing methods and conditions.

Cost of Artificial Propagation

A summary of all operations and the time involved for each was presented for these two experiments as far as they had progressed by the end of October, 1938. Some of the larvae had not at that time reached maturity and consequently required further attention during the following spring and early summer. The total time involved up to the development of new adults amounted to somewhat more than 400 man-hours for 1,000 T. virescens. Since these rearings were started, new time saving improvements have been developed, so this period may be considered maximum. With these new improvements in technic, the estimated time required is 300 man-hours per 1,000 T. virescens when fed every 2 days on D. monticolae larvae. In large quantity rearings the time required per 1,000 may be reduced by 50 percent.

The greatest single time consuming item required in rearing these predators is brought about by the necessity of handling and treating each one individually because of cannibalism. No methods have yet been developed to overcome this difficulty.

2. Comparative Prolificness of Laboratory and Field Reared T. virescens Adults.

Production of Eggs

Three lots of paired adults were established for the purpose of oviposition during the summer at the Miami Laboratory. All pairs were set up in pint size jars which contained a thin layer of sawdust on the bottom. A small, white crepe paper roll tightly would in overlapping layers, was placed in each jar, where it stood on end. The selection of adult pairs for mating was done by use of the submental pit present only on the male.*

One lot of adults originated from laboratory reared specimens developed at Berkeley on fly larvae. The second lot was taken at random from infested trees in the vicinity of the Miami Laboratory. The third lot originated from laboratory reared specimens developed at the Miami Laboratory on D. monticolae larvae. Each lot was set up at a different time. Those brought from Berkeley were set up on May 2. The field specimens were set up on June 26, 1939. The Miami specimens were not ready to be set up until August 2. The results are presented in Table 8.

Table 8. Comparative Number of Eggs of T. virescens Originating from Three Sources.

Series Number	Source	Period of Test, 1939	No. of pairs set up	No. productive pairs	% productive pairs	Total no. eggs	Average no. eggs per pair
1	Berkeley	5/2-9/20	42	19	45	1,135	59.7
2	Field	6/26-9/20	33	11	33	625	56.8
3	Miami	8/2-9/28	100	67	67	2,825	42.1

No appreciable difference was noted in the number of eggs produced per pair regardless of the origin of adults. Laboratory reared adults had a higher percentage of productive pairs than those collected from the field, but this is to be expected since they had never had a chance to oviposit before the start of the test and hence would have the full complement of eggs.

Adults reared on flies at Berkeley produced as many eggs as those reared on their native host food. Owing to the short oviposition period of the third group, the full number of eggs could not be expected, and hence it is unfair to compare the average number per pair with groups 1 and 2 which produced their eggs over a much longer period. The full complement of eggs of all groups had not been reached during the course of the tests, since the average production is much below the average for previous tests conducted for the full duration of adult life.

* See references cited.

Viability of Eggs

Previous records based on 125 eggs laid by field reared adults showed that the average viability for the group was 69 percent.

Further opportunity to obtain information on egg viability, especially of those produced by laboratory reared adults, was provided during 1939. Records were kept on 15 different groups of eggs totalling 2,114, all laid by laboratory reared adults. The average fertility for this number of eggs was also 69 percent. In individual groups the fertility varied between 53 and 95 percent.

These results indicate that the fertility of adults, regardless of source, is approximately the same and that 70 percent of the eggs laid will hatch.

Oviposition in Relation to Temperature

The number of eggs laid by T. virescens females is apparently influenced considerably by temperature. The evidence of this belief is based partly on observation and partly on data obtained from laboratory oviposition tests. Adult T. virescens are found at any time during the winter, but there is no evidence that they lay eggs then, on young overwintering D. monticolae broods in sugar pine.

In the laboratory at Miami the number of eggs laid by series 1 (Table 8) during weekly intervals varied according to temperature increased above 80° F. As can be seen in the graph (Figure 1) egg production practically remained at a stand still until after the middle of June, when there was a definite rise. This increase was found to be quite definitely correlated with a rise in temperature during the day above 80° F. The number of eggs laid fell off sharply during August, even though the temperature remained high, but it is assumed that the supply of eggs had by that time become exhausted.

3. Possible Causes of Short Larval Development Period

Rearing experiments and observational data have shown that the total life cycle of T. virescens is much too long and variable on the average to expect effective control of the mountain pine beetle. They have also shown that, occasionally short term individuals are developed which show marked synchronism with the host. If the causes for rapid development can be isolated and propagation technic can be developed to rear them in numbers, much greater promise may be expected in the development of biological control by use of this species. Two methods of approach to this problem were tried out during the 1939 field season.

Development of Larvae in Relation to Amount of Host Food Consumed

The possibility that short term generations of T. virescens may be influenced by the amount of host food eaten suggested an experiment in which varying amounts of D. monticolae larvae were given to designated groups of newly hatched T. virescens larvae. In this experiment 5 groups of 25 larvae each were set up August 18, 1939 and were fed at varying intervals from 1 to 5 days apart. The first group was fed every day, the second every two days, and so on. This schedule was maintained except for 2 minor interruptions of a few days each until January 11, 1940. After the 15th of October the larvae were moved to Berkeley and the feeding schedule was maintained there.

The host food given was fully grown D. monticolae larvae. One larva was given to each predator on the scheduled feeding date.

From the beginning of the test a marked variation in size was apparent. The larvae fed every day were the largest while those fed every 5 days were the smallest. (Figure 2). Toward the end of the feeding period in January, 1940, there was a tendency noted for the larvae fed less frequently to catch up with those fed more often. No shortening in the period of development was found. None of the larvae had pupated by February 13 after a lapse of 179 days since the beginning of the test.

The conclusion to be drawn from this test is that the amount of food consumed is not correlated with short term development, but instead the extra food tends to produce larger individuals.

Development of Progeny Larvae Originating from Short Term Adults

In this experiment adults were secured by rearing them from pupae which had developed in a ponderosa pine killed in 1939 by D. brevicomis. The pupae had developed at the time the D. brevicomis brood had nearly completed total emergence. Since the new D. brevicomis brood was the only one developed in this tree there could be little doubt as to the short development of the T. virescens pupae found there.

Eight adults were reared from the pupae collected. Because of an inequality in sexes only two pairs could be set up for producing eggs. The first eggs were laid on August 28. A total number of 29 larvae hatched from the eggs laid by one of the two pairs, were set up under artificial rearing conditions in glass vials by September 20. Fully grown D. monticolae larvae were fed at the rate of 1 per day from the start of the test with few interruptions until January 11, 1940. They were left since then unfed, at a constant temperature of 75° F. at Berkeley and showed no signs of pupating on the 13th of February, 1940.

The conclusion to be drawn from this test is that the short term life cycle is not the result of an inherent strain, but it may be influenced by the kind of host food upon which it is able to feed. D. brevicomis may be the answer to this question.

Summary and Conclusions Regarding Artificial Propagation

The investigative work on artificial propagation of native predators of the mountain pine beetle have thus far determined in part the possibilities and limitations of E. sphegeus and T. virescens in relation to the development of biological control. While this work is yet incomplete, it is appropriate at this point to sum up the accomplishments on the completed phases in order to clarify and determine what practical possibilities there may be in planning a program for further study. Thus far the following completed phases are pointed out, weaknesses discussed, and possibilities indicated.

1. Laboratory methods and equipment were developed which are highly satisfactory in the production of T. virescens from egg to adult on native host food. No satisfactory supplementary food has as yet been developed, but considerable promise is offered by fly larvae (L. sericata) fed to all stages of T. virescens beyond the first stage. By use of Drosophila larvae it may be possible to rear the younger T. virescens to a point where they can be fed satisfactorily on L. sericata.

2. By use of the same technic and methods of rearing, E. sphegeus was found to respond too poorly to make it worth while to continue experiments with this insect. No supplementary hosts were found on which it would live. Unless a technic adaptable to this insect can be developed, there is no hope in developing it artificially.

3. Although T. virescens can be developed successfully in the laboratory in numbers far in excess of the normal population increase, the rearing costs are entirely out of proportion to the amount of benefit that can be derived. Unless mass artificial rearings can be made at a cost in proportion to benefit, we must dismiss this insect from further consideration here.

4. The high cost in the development of this insect is brought about partly by the necessity of individual treatment in rearing. The larvae can not be reared in masses because they are highly cannibalistic, showing no choice in food between their own kind and the host, even in an abundance of available host food. This characteristic is equally true of both predators.

5. The cost of rearing is increased further by the necessity of rearing native host food. With the development of supplementary hosts the extra cost may be greatly reduced.

6. No synchronism exists between the development of Temnochila and the mountain pine beetle. Thus under natural conditions, in order to survive, this predator is forced to feed upon supplementary hosts, resort to cannibalism, or perish. Therefore, the benefits which may be derived from increased populations through artificial propagation are largely nullified. The exception to this may be found in investigations of the causes and possibilities of short term development.

7. While there is strongly synchronized development between E. sphegeus and the overwintering populations of D. monticolae, there is no development on summer populations. Consequently this predator could not be relied on as a highly effective controlling agency even if it were adaptable to artificial propagation to increase populations.

8. Since neither of the predators is specific to one host, artificial propagation in the long run could not be directed toward the control of any specific host. Liberated predators would show no particular specificity. The controlling effect would therefore be divided up among the several hosts prevalent in the vicinity of liberation.

Considering the eight points presented here it appears that the possibilities in artificial rearing are few as applied to the two species. Further studies, however, should be undertaken to determine (1) the possibilities in developing an adequate host or hosts at low cost, and consequently reduce the cost of artificial rearing, (2) to investigate further the causes and possibilities in the development of the short term cycle of T. virescens, (3) to investigate further the possibilities of the artificial propagation of other species of predators in the development of biological control.

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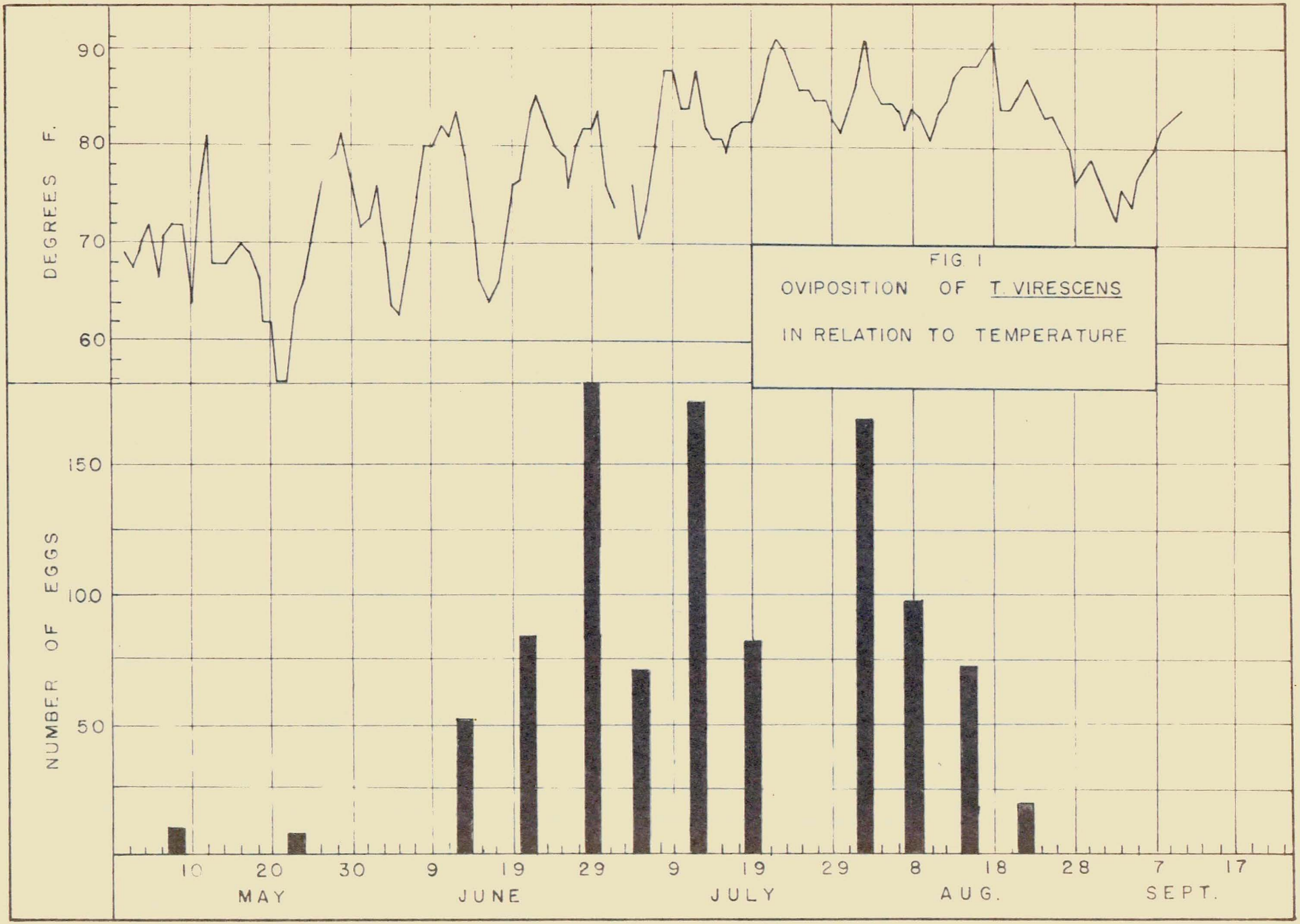

FIG. 1
OVIPOSITION OF T. VIRESCENS
IN RELATION TO TEMPERATURE

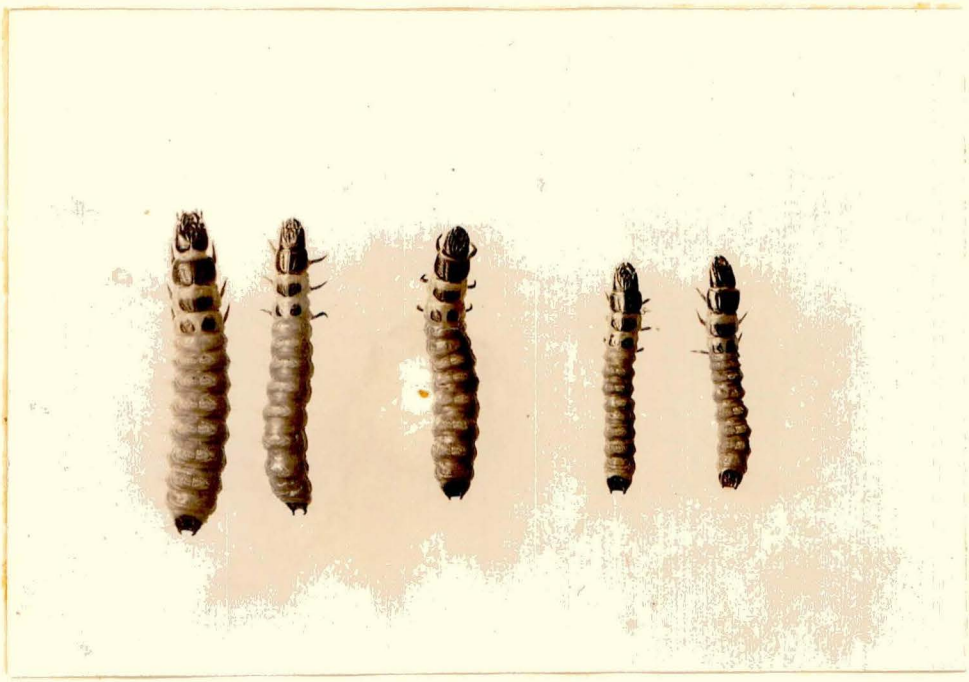

Figure 2. These T. virescens larvae are representative specimens from 5 lots reared artificially to test whether the amount of host eated would determine or influence the period of development. The larva at the extreme left was fed one mature D.m. larva every day; the one at the extreme right was fed every 5 days. The intervening larvae were fed every 2, 3 and 4 days respectively. The only difference found between the groups in relation to the amount of food was a variation in size.